SOIL MANAGEMENT FOV$SUSTAINABLE FOOD PRODUCTION IN TAIWAN

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ABSTRACT

Under Taiwan's subtropical conditions and intensive cropping systems, soils suffer from a low pH, and a low organic matter and nutrient content. Chemical fertilizers are used to increase crop production, and good yields have been obtained in past years. However, other soil properties such as low pH, low organic matter content and poor drainage are not being treated by farmers, and are becoming an obstacle to soil productivity. Soil management strategies such as liming, fertilizer recommendations based on soil testing and plant analysis, crop rotation, breaking the hard-pan, and the application of organic materials and biofertilizer are being adopted for sustainable agricultural production in Taiwan.

CHARGES IN TAIWANS AGRICULTURE SINCE 1945

The development of Taiwan's agriculture over the last fifty years can be divided into three stages. From 1945, following the Japanese occupation, to 1952 was the first stage. The government executed policies such as land reform, construction of irrigation systems, distribution of chemical fertilizers, release of high-yielding varieties and extension of new agricultural technology. Agricultural production increased rapidly and was restored to prewar levels. The aim of these programs in the first stage was to grow enough staple foods to meet domestic needs. The second stage was from 1952 to 1968, with four-year economic construction plans. Agricultural production was accompanied by industrial and general economic development. The government launched programs emphasizing multiple cropping, intensive use of fertilizer, and crop protection. The aim during this second stage was to produce high yields of better quality products such as rice, sugar and bananas for export, in order to earn foreign exchange for national industrialization. From 1968 up until the present might be called the third stage, during which there was a more gradual development of industry and international trade. Farmers' incomes have been low compared to those in other sectors, and agricultural productivity has been declining. The government has launched several polices, such as "Accelerated rural construction", "Increased farm incomes" "Improvement of agricultural infrastructure to maintain farmers' incomes", etc.. The aim of these programs has been to sustain agricultural development.

Taiwan's agriculture has done a tremendous job of producing enough food for the people, and of earning money to fund the development of industry. As in other industrialized countries, farmers in Taiwan rely more on chemical fertilizers and pesticides than on traditional renewable resources drawn from the farm itself. The cultivation methods typical of modern agriculture in Taiwan have aroused public concern over environmental problems such as the contamination of water with agricultural chemicals, pesticide residues in food, growing resistance to pesticides among insects and pests, loss of natural soil productivity and aggravated salinity.

In recent years, "sustainable agriculture" has become a topic which has received great attention from environmentalists, agricul-turalists, and consumers. Sustainable agri-culture has been given a number of different definitions, but the term implies three basic values: sustainable agriculture is ecologically sound, economically viable, and socially just and humane. In term of agricultural technology, the

Keywords: crop rotation, hard-pan, liming, organic fertilizer, plant analysis, soil fertility status, soil management, soil testing, Taiwan.

major components of sustainable agriculture are cultural practices and plant breeding, soil and water management, non-chemical pest and weed control, integrated plant-animal production, and nutrient recycling.

Soil is the fundamental natural resource of agricultural production. Good soil management is the basis for sustainable food production.

Changes in Soil Management

At the end of World War II, farmers in Taiwan were making little use of chemical fertilizers. The total consumption of chemical fertilizer in Taiwan in 1945 was only 5,789 mt, so farming had to depend mainly on natural fertility and organic manure. Currently, Taiwan's farmers use approximately 1,400 thousand mt of chemical fertilizer (equivalent to 400 thousand mt of nutrients (Table 1) with percentage rates of N-P_2O_5-K_2O at 60%, 15%, and 25%, respectively). The average fertilizer application rate is 500 kg/ha, (in nutrients), one of the highest rates in the world (Table 2). Before 1970, almost 80% of the total fertilizer distributed was used for rice production. With the adoption of the rice diversification program, the fertilizer used for rice declined to less than 40% of the total, and the fertilizer used for upland crops rose to almost 60% of the total.

At present, farming in Taiwan uses high inputs of fertilizers and pesticides, and is highly mechanized. This high level of inputs is mainly derived from non-renewable petrochemical energy. At the same time, its effect on soil productivity is a subject of great concern.

FERTILITY STATUS OF TAIWAN'S SOILS

Soil fertility status is defined as the ability of a soil to supply elements essential for plant growth without a toxic concentration of any element. Soil pH, organic matter content, texture, and the nutrient content of the soil are important parameters related to soil fertility.

As in all tropical and subtropical countries with year-round warm temperatures and high annual rainfall, the soils of Taiwan are constantly subject to rapid chemical decomposition and leaching. The depletion of soil fertility on much of Taiwan's culti-

Table 1. Fertilizer consumption in Taiwan Unit: mt

Fertilizer	1987	1988	1989	1990	1991	1992
N	231,712	251,124	249,743	254,968	269,231	259,405
P_2O_5	65,193	66,754	69,250	71,909	72,849	72,768
K_2O	98,156	97,737	99,756	100,767	106,120	105,553
Total	395,061	415,615	418,749	427,644	448,200	437,726

Source: Council of Agriculture, Taiwan ROC

Table 2. Fertilizer consumption per hectare in Taiwan Unit: kg/ha

Nutrient	1987	1988	1989	1990	1991	1992
N	261.4	280.6	279.2	286.5	304.7	296.0
P_2O_5	73.6	74.6	77.4	80.0	82.4	83.0
K_2O	110.8	109.2	111.5	113.2	120.1	121.0
Total	445.8	464.4	468.1	480.5	507.2	500.0

Source: Council of Agriculture, Taiwan ROC vated land is aggravated by the highly intensive land use, whereby two to three crops or more are grown and harvested each year.

The distribution of soil organic matter in Taiwan in different classes is summarized below (Lin 1967). These classes are based on an analysis of 78,000 soil samples, each sample representing 10 ha of cultivated land.

Organic matter (%)	% distribution
0-1 (very low)	14
1-2 (low)	51
2-3 (medium)	27
More than 3 (high)	8

As shown above, 65% of Taiwan soils contain less than 2% organic matter. Since soil organic matter is closely related to the supply of available soil nitrogen, most soils in Taiwan are deficient in nitrogen.

The percentage distribution of acid and alkaline soils in of Taiwan is given below:

Soil pH	% distribution
Below 5.5 (strongly acidic)	33
5.6-6.5 (moderately acidic)	25
6.6-7.3 (neutral)	16
7.4-8.0 (slightly alkaline)	22
More than 8.0 (alkaline)	5

The data show that strongly acidic soils cover one-third of the cultivated land area of Taiwan. Application of lime to correct these acidic soils is important.

The"soil phosphorus status of Taiwan's soils (according to their contents of available phosphorus (Bray's P1)) is given below:

Available P ppm	% distribution
0-4 (very low)	7
5-10 (low	30
11-20 (medium)	32
More than 20 (high)	31

This shows that 79% of Taiwan's soils have an available phosphorus content (Bray's P1) of less than 20 ppm.

As for the potassium status, the distribution of Taiwan's soils according to their content of available K (Mehlich's method) is given below:

Available K ppm	% distribution
0-15 (very low)	4
16-35 (low)	37
36-80 (medium)	43
More than 80 (high)	16

This indicates that 84% of Taiwan soils contain less than 80 ppm available K.

Obviously, natural soil fertility is low in Taiwan. There is an urgent need to correct poor soil properties so as to sustain agricultural production.

SOIL MANAGEMENT PROBLEMS

Soil Nutrient Balance

In a natural ecosystem, the 16 elements essential for plant growth are kept in balance. The amounts required by the plants are matched by those supplied naturally by the soil. The purpose of fertilization is to remedy a deficit of soil nutrients. Under Taiwan's intensive cropping systems, farmers apply a large amount of chemical fertilizer. Nitrogen, potassium and phosphorus fertilizers are the most common (Table 3). However, farmers in Taiwan tend to apply more N, P and K, especially N, than is required by the crop. An excessive amount of fertilizer is often found in the soil. Thus, agricultural practices have changed the soil nutrient balance.

Other Aspects of Soil Fertility

As well as soil nutrients, other factors such as soil reaction (pH), aeration, structure, depth and drainage affect soil productivity. With Taiwan's year-round warm temperatures and high precipitation, most soils (apart from some alluvial soils) are acidic to strongly acidic. Of the strongly acidic soils, there are about 280 thousand ha of farmland with a soil pH below 5.5. The western coastal area has a salinity problem. Precipitation is uneven, and there is a high evaporation rate throughout the year. Overpumping of groundwater has caused sea water to seep into inland soils. During the summer season, typhoons drive sea water inland to flood the coastal plains. This has created a total of about 20 thousand ha of saline and alkaline soils.

Protected cultivation has become popular in recent years. So far, there are about 500 ha where vegetables are grown in greenhouses, shadehouses and other types of structure. In protected cultivation, rain does not reach the soil, so there is no natural leaching. Farmers nearly always apply an excessive amount of fertilizer. A large amount of soluble salts accumulates as a residue, and a man-made saline soil is formed.

Before 1972, Taiwan's agricultural policies emphasized rice production. Preparation of saturated soils destroyed the soil structure. Fine clay particles migrated down and accumulated at the bottom of the plow layer. At the same time, draft animals and farm machinery were compacting the soil during these farm operations. After some period of time, a hardpan formed in paddy soils at a depth of 20 to 40 cm (Table 4). This hardpan acts as a barrier to drainage, and restricts the root penetration of upland crops.

Soil reaction, salinity, structure and hardpans are the main soil problems in current agricultural production.

Methods of Fertilizer Application

Fertilizers are required to supply the needs for plant growth and absorption. The rate, timing and placement of fertilizer applications determines their effectiveness. Basal or top-dressing, broadcasting and strip or spot application, are widely used as a means of supplying needed nutrients. Since farms in Taiwan are too small for conventional farm machinery, most fertilizer operations are carried out manually. In recent years, the development of industry and trade has attracted rural workers to the cities. Wages have increased rapidly, and have become the main cost in agricultural production (Table 5). In contrast, the fertilizer supply and prices are controlled by the government, and are very stable. The cost of fertilizer in agriculture production is low compared to the cost of labor. In order to reduce production costs, farmers do not follow recommended methods of applying fertilizer.

Since most fertilizers are applied to the soil surface, there is loss of nutrients by evaporation and run-off, while contaminated groundwater has become a major concern.

Table 3. Fertilizer use by farmers' and recommended rates for main crops in Taiwan

	Farmers' rate			Recommended rate		
Crop	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Rice	161	56	86	127	55	57
Corn	215	67	106	175	95	70
Sorghum	182	54	82	130	60	50
Soybean	70	30	50	50	75	53
Peanut	76	32	73	20	53	60
Sweet potato	117	47	176	60	50	150
Green onion	363	258	201	180	110	175
Cauliflower	369	112	117	275	140	200
Cabbage	608	162	147	300	80	150
Banana	507	178	557	378	165	847
Pineapple	649	153	514	600	110	450
Grape	250	315	267	140	200	420
Citrus	488	404	415	400	200	300

Source: *Taiwan Agriculture Yearbook*, 1980

SOIL MANAGEMENT FOR SUSTAINABLE AGRICULTURE

Soil quality includes such factors as organic matter content, the biotic activity of the soil fauna, soil structure and water infiltrability, porosity and pore-size distribution, cation-exchange capacity, pH, concentration of toxic elements, the presence of any nutrient imbalance, etc. Improving soil quality for better plant growth has long been a primary objective of soil science. However, many problems of soil quality remain in Taiwan. A loss of soil quality can result from poor management of soil resources, in the absence of information on how to manage them properly. Proper soil management strategies are necessary if agricultural production is to become sustainable.

Reclamation of Acid Soils

Soils are acid either because their parent materials were acid and low in basic cations (Ca, Mg, K, and Na), or because these elements have been removed from the profile by leaching or by the repeated harvesting of crops (Kamprath and Foy 1972). Soil acidification is intensified by the use of acid-forming nitrogenous fertilizers (Pierre *et al.* 1972), and by acid deposition from polluted air (Ulrich *et al.* 1980). Growth-limiting factors that have been associated with an acid soil infertility complex include toxicities of A13+, Mn2+, and other metal ions, low pH (H toxicity), and deficiency or unavailability of certain essential elements, particularly Ca, Mg, P and Mo (Jackson 1967; Kamprath and Foy 1972).

The 280 thousand ha of arable land in Taiwan with a soil pH of less than 5.5 are generally low in available silica. Application of siliceous material should therefore constitute an integral part of soil fertility management for rice, which requires silica for normal growth. The critical concentration of available SiO_2 in soil, (extracted by 1N NaOAc at a pH of 4.0) is about 40 ppm for rice. About 60% of the soils which have a pH below 5.8 have a silica content of less than 40 ppm.

Once the silica content falls below this level, rice will generally respond to an application of siliceous slag. The application of 2.5 mt of a material containing 22% 1/2 N-HC1 soluble SiO_2, gives a yield increase of 5% or more (Wu and Lian 1965).

Liming to correct soil acidity is also very important. However, several field experiments conducted in recent years on latosolic paddies and sandstone/shale alluvial soils in northern Taiwan have shown little or no effect from liming (Chen 1971, Chiu and Peng 1971). Dryland crops such as soybean and peanut tend to show a relatively marked response to lime (Su 1972). The application of 2-4 mt lime/ha can give a yield increase of 7-107%. A reclamation program for acidic soils has been established, to encourage farmers to apply liming materials to strongly acidic farmland. Under this program, applications of 2-3 mt/ha of siliceous slag or slaked lime are recommended. The final retail price when farmers purchase siliceous slag is NT$1.8 per kg, 50% of which is subsidized by the government while the farmer pays the rest. So far, the program covers 14,000 ha of acidic arable land which is now in the process of reclamation.

Table 4. Bulk density (g/cc) and presence of plow pan in four soil series

Depth (cm)	Red soil	Slate alluvial	Sandstone shale	Alluvial
0-20	1.28	1.24	1.28	1.31
20-40	1.72	1.61	1.41	1.60
40-60	1.68	1.43	1.46	1.57
60-80	1.60	1.46	1.56	1.66
80-100	1.57	1.38	1.36	1.61
Plow pan*	1.76	1.58	1.58	1.70
Plow pan**	1.90	1.75	1.59	1.87
Depth (cm)	21-25	28-35	25-32	18-23
Thickness (cm)	3-4.5	1.5-2.5	1.5-2.5	1.6-3

* : Core method
** : Paraffin method

Source: Chen 1988

Table 5. Cost analysis of rice production

Year	Total cost of production (US$/ha)	Share in total cost (%)		
		Fertilizer	Labor	Others
1940	902	19.47	45.32	35.21
1945	206	25.79	41.38	32.83
1955	483	22.75	45.15	32.10
1965	1639	8.36	51.01	40.63
1975	2825	8.67	56.92	34.41
1981	3465	6.15	62.58	31.27

Source: Taiwan Provincial Food Bureau
Notes: (1) Mean of 1st and 2nd crops.
(2) Fertilizer includes chemical and organic fertilizer.
(3) Labor includes human, animal and machinery power

Use of Organic Matter

Organic matter used for agriculture in Taiwan can be classified into the following categories: crop residues, green manure, compost, animal wastes, municipal refuse, oil cake, and residues from food processing (Hsieh and Hsieh 1989). Of these, crop residues and animal wastes are the major sources. In traditional farming, most animal wastes were returned to cropland. One cow produces about 30 kg of wastes every day, while pigs and poultry produce 6 kg and 0.15 kg, respectively.

The total annual production of animal wastes in Taiwan is estimated to be 22.21 million mt (Table 6). This is enough to cover the whole area of agricultural land at a rate of 25 mt/ha, and could substitute for 61% of the nitrogen applied in the form of chemical fertilizer in 1992, as well as 173% of the phosphorus and 89% of the potassium.

If we assume that the maximum rate at which animal wastes should be applied is 50 mt/ha, the total amount produced in Taiwan would suffice for 444 thousand ha. However, most livestock wastes are not used for agriculture, but are discharged into streams, to become a pollutant of Taiwan's waterways.

At the same time, as previously stated, organic matter decomposes rapidly under warm climatic conditions and most soils in Taiwan have a low organic matter content of less than 2%. There is an urgent need to recycle organic matter efficiently, increasing or at least maintaining the soil organic matter content, and substituting organic for chemical fertilizer, in order to prevent water pollution and improve soil fertility.

Nutrient Management

Testing of both soil and plants can be used to evaluate the status of soil fertility and plant nutrition. Two primary purposes of the tests are to make fertilizer recommendations, and to measure the effectiveness of fertilizer practices.

Recommended rates of P and K based on soil tests have been studied by many workers (Wang 1966, Sheng *et al.* 1964, Juang and Fang 1966). The results of studies on the correlation between response of various crops to applied P and K fertilizer and the available P and K content of the soil have been summarized by Su (1972) (see Table 7).

Recommended rates of fertilizer for fruit trees, particularly citrus, based on plant leaf analysis, have also been intensively studied in recent years (Chang *et al.* 1992). The optimal ranges of nutrient concentrations in the leaves of fruit trees are listed in Table 9.

Around 5000 soil and 1500 plant samples were taken and analyzed by the Taiwan Agricultural Research Institute and six District Agricultural Improvement Stations. Reports of the analysis and fertilization recommendations were sent directly to the grower. The overuse of fertilizers and a consequent nutrient imbalance are often found in fields with crops of high economic value such as fruit and tea. A program called "Application of soil and plant diagnoses for orchards and tea plantations" has been carried out since 1987. The fruit trees include grape, citrus, wax-apple, pear, peach, carambola and loquat. Five hundred orchards and tea plantations from major growing areas have been selected as demonstration areas.

Crop Rotation

Systems of crop rotation offer many advantages in terms of improved soil properties and the control of weeds, erosion and various pest species. Crop rotation has long been utilized very successfully in traditional agricultural production systems in Taiwan. However, crop rotation was not emphasized in modern rice production until 1975, when the importance of rice production began to decline. Farmers following the most popular cropping pattern of that time, two crops of rice and one dryland crop, were advised to convert to one crop of rice and two dryland crops, or dryland crops alone (including a fallow period).

In order to determine soil fertility status under various crop rotation systems, long-term field experiments have been carried out in various parts of Taiwan. The results indicate that the rotation of one crop of rice with upland crops (corn or soybean) was better than three upland crops for maintaining soil pH and organic matter content (Hsieh 1992) (Table 10). Including legumes such as soybean or sesbania in the rotation sequence contributes nitrogen to the succeeding crop (Tsai *et al.* 1989). The proper utilization of legumes as green manure helps improve soil fertility for better crop production. Suggested rotation sequences for maintaining soil productivity are: wet followed by dry cultivation; legumes and non-legumes; deep- and shallow-rooted crops; and crops with a high nutrient demand followed by crops with a lower one.

Tillage

The purpose of tillage is to improve soil physical properties for root growth, and to remove the weeds which are competing with the crop for water, space and nutrients. Conservation tillage is a form of low-input agriculture, in that it requires a lower input of energy and labor, and minimizes disturbance to the soil (Allmaras *et al.* 1991). However, whether reduced tillage gives good results partly depends on the soil type. It is not suited to soils with a plow pan, or the compacted subsoil caused by repeated plowing and puddling of paddy fields. A hard plow pan with a bulk density of as much as 1.59 - 1.9 g/cc is considered a limiting barrier to root penetration and drainage (Chen 1988).

The reclamation of soils with an impervious hard pan below the plow layer has been studied (Lian 1988, Chen 1987). A hard pan, poor drainage and low phosphate availability are the most serious limiting factors that constrain the development of the rooting system of upland crops grown in paddy fields, and subsequently reduce the yield. Deep ploughing along the plant row, leaving the subsoil intact between the rows, with deep banding of fertilizer, was conducted by a mechanized planter-fertilizer applicator with attached subsoilers. At the same time, two-thirds of the basal fertilizer was applied in a band at a depth of about 25 cm, and the remaining one-third 5 cm from the seed row. A yield increase of 11-25% was obtained while using 20% less nitrogenous fertilizer (Table 11) (Lian 1988).

About one half of the effect can be attributed to that of the deep ploughing, which was more effective at a depth of 25 cm than at only 12.5 cm (Table 12).

Table 6. Annual production of animal wastes in Taiwan, 1989

Animal	Daily waste Production (kg/day/head)	No. of animals (1,000)	Annual waste production (10^6 mt/year)	Nutrient production (1000 mt/year) N	P_2O_5	K_2O
Cattle	30	176	1.93	8.7	4.8	11.6
Pigs	6	6,954	15.23	106.6	91.4	60.9
Poultry	0.15	92,292	5.05	44.0	30.3	21.7
Total				159.3	129.5	94.2
	Equivalent to % annual chemical fertilizer consumption			61.4	173.8	89.2

Table 7. Recommended rates of phosphatic fertilizer for various levels of soil available phosphorus

Crop	Type of soil	Available P		P_2O_5 rate (kg/ha)	
		Method	ppm	1st crop	2nd crop
			0-4	60-80	40-60
Rice	Latosol and alluvial	Bray 1	5-20	30-60	20-40
			> 20	20-30	0-20
			0-3	90	
Sweet potato	Non-calcareous alluvial	Bray 1	3-9	60	
			9-30	30	
			> 30	0	
			0-15	60-90	
Corn	Sandstone/shale and schist alluvial	Bray 1	16-30	30-60	
			> 30	0-30	
			0-100	50-70	
Tobacco	Sandstone/shale alluvial	Dyer	100-150	30-50	
			>150	0-30	
Tea	Latosol	Bray 1	0-3	20-40	
			> 3	0-20	

Source: Su 1972

Table 8. Recommended rates of potash fertilizer for various levels of soil available potassium

Crop	Type of soil	Available K		K_2O rate (kg/ha)	
		Method	ppm	1st crop	2nd crop
			0-15	50-70	70-90
	Latosol & alluvial combined	Mehlich	16-45	30-50	40-60
			> 45	0-30	0-40
Rice					
			0-50	50-80	
	Latosol	Exchange-able	51-70	30-50	
			70-100	0-30	
			> 100	0	
			0-20	240	
Sweet potato	Sandstone/shale alluvial (calcar. & non-calcar.)	Egner	21-30	180	
			31-40	120	
			41-60	60	
			> 60	0-60	
			0-35	50-75	
Corn	Sandstone/shale & schist alluvial	Mehich	36-70	25-50	
			> 70	0-25	
			0-35	600-750	
Pine-apple	Acid soils	Exchange-able	36-70	450-600	
			71-105	300-450	
			105-140	150-300	
			> 140	0-150	

Source: Su 1972

Table 9. Critical concentration of nutrient elements in the leaves of fruit trees

Nutrient element	Grape Summer	Grape Winter	Citrus	Pear	Loquat	Peach
N	2.1-2.6	2.4-2.8	3.0-3.2	2.0-2.6	1.4-1.6	2.0-3.3
P	0.16-0.22	0.16-0.22	0.12-0.18	0.12-0.20	0.12-0.20	0.12-0.14
K (%)	0.7-1.2	0.9-1.6	1.4-1.7	1.2-2.0	1.0-1.8	1.2-2.0
Ca	1.0-2.0	2.0-2.7	2.5-4.5	1.25-2.00	0.8-1.5	2.3-3.0
Mg	0.26-0.50	0.26-0.50	0.26-0.50	0.27-0.50	0.18-0.30	0.25-0.5
Fe	70-120	70-120	60-120	35-200		
Mn	25-200	25-200	25-200	30-200		
Zn (ppm)	26-140	26-140	25-100	20-90		
Cu	5-20	5-20	5-16	10-20		
B	30-100	30-100	25-150	20-150		

Table 10. Changes in soil pH and organic matter content under various cropping patterns in Taiwan

Rotation sequence		Year 1	2	3	4	5	6
Rice-rice-fallow	pH	6.2	5.8	5.5	5.5	5.5	5.8
	% OM	1.16	1.05	1.48	0.95	1.04	1.4
Rice-soybean-corn	pH	6.3	5.9	5.9	5.4	5.8	6.0
	%OM	0.96	1.10	1.14	1.05	0.95	1.38
Sorghum-ratoon-corn-sorghum	pH	6.1	4.8	5.1	4.7	4.3	4.7
	%OM	1.57	1.02	1.12	1.20	0.97	1.38
Sorghum-soybean-corn	pH	6.3	4.3	5.2	4.9	5.2	5.1
	%OM	1.66	1.32	1.12	1.05	0.87	1.35

Source: Hsieh *et al.* 1992

Table 11. Effect of in-row deep ploughing with deep banding of fertilizer on corn yield with tillage and no-tillage

Tillage / N(kg/ha) / Placement	Tillage 150	Tillage 210	Tillage Mean	No-tillage 150	No-tillage 210	No-tillage Mean
Ordinary	4.65c	4.77c	4.71c	4.73a	4.95a	4.84a
In-row subsoiling, deep banding	5.53a	5.81a	5.67a	5.19a	4.95a	5.07a
In-row subsoiling, ordinary placement	5.01b	5.32b	5.17b	4.93a	4.79a	4.86a

Source: Lian 1988

Table 12. Effects of different depths of in-row subsoiling with deep banding of fertilizers on the yield and yield components of corn under tillage and no-tillage

Placement	Yield (mt/ha)			No. grains $10^3/m^2$		g/1,000 grains	
	Tillage	No-tillage	Mean	Tillage	No-tillage	Tillage	No-tillage
Ordinary	4.95c	4.77c	5.28c	1.78	2.07	277	282
In-row subsoiling, deep banding (depth 25 cm)	6.61a	6.58a	6.59a	2.40	2.27	284	286
Ibid (depth 12.5 cm)	5.73b	6.32b	6.03b	2.00	2.19	297	281

Source: Lian 1988

Table 13. Effect of inoculations of VA mycorrhiza (VAM), rhizobia (R), and P-solubilizing bacteria (PSB) together with applications of superphosphate (SP) and rock phosphate (RP) on peanuts

Inoculation	Phosphate treatment (kg/ha)	Hualien, (East coast) (kg/ha)	Yuancharng (Southwest Taiwan) (kg/ha)
Control	0	1875 b (100)	3667 c (100)
Control	SP (330)	2250 a (120)	2625 c (99)
Control	RP (660)	2250 a (120)	6167 a (168)
VAM	0	2350 a (125)	6208 a (169)
VAM	RP (660)	3367 a (126)	5125 b (140)
PSB	0	2259 a (120)	6333 a (173)
PSB	RP (660)	2275 a (121)	6083 ab (166)
R	RP (660)	2400 a (128)	6083 ab (166)
R + VAM	0	2433 a (130)	6000 ab (163)
R + VAM	RP (660)	2467 a (132)	6083 ab (166)
R + VAM	RP (660)	2533 a (133)	6750 a (184)
R + PSB + VAM	RP (660)	2550 a (136)	6458 a (176)

1. Duncan's multiple range test (P = 0.05)
2. % of control

Source: Young 1990

Table 14. Effects of rhizobia inoculation on vegetable soybean

	Chemical fertilizer ($N-P_2O_5-K_2O$ kg/ha)	Nodules	Effective (%)	Yield (kg/ha)	Comparison (US$/ha)
Ordinary	176-166-164	14.9	40.7	8,240 (100)	0
NPK	60-60-60	14.3	42.6	8,609 (105)	+276
Inoculated	20-60-60	18.2	54.9	9,491 (115)	+625

Source: Kaohsiung DAIS 1988

Biofertilizer

Soil microorganisms play an important role in the nutrient cycle of the soil. In order to reduce the applications of nitrogen fertilizers and the pollution problems they cause, research into the use of biofertilizers has been carried out in recent years. Rhizobia, VA mycorrhiza and P-solubilizing microorganisms have been isolated and studied. The results showed that biofertilizers increased the growth and yield of soybean, peanut and leucaena in pot and field tests (Table 13) (Young 1990). At the same time, we also found that the use of VA mycorrhiza increased the yield and quality of muskmelon (Cheng 1985). In order to encourage farmers to use biofertilizers, an extension program has been established. Inoculates of rhizobia and mycorrhiza are produced by universities and government institutes, and distributed to soybean and muskmelon growers. So far, around 3000 ha of vegetable soybeans and 500 ha of muskmelons are inoculated with biofertilizers each year. In one part of Taiwan where vegetable soybean growers have been applying nitrogen fertilizer at rates as high as 174 kg N/ha, the inoculated fields needed only 20 kg N/ha (Table 14).

CONCLUSION

By the use of large amounts of chemicals and high-yielding varieties, successful agricultural production has been achieved in Taiwan over the past four decades. However, continuous applications of chemical fertilizer without due regard for the soil and crop conditions have resulted in nutrient imbalances, poor quality produce, and environmental pollution. Under the threat of depleted resources of nonrenewable energy, soil management will play an important role in sustainable food production.

Through the use of soil testing and plant analysis, a sophisticated fertilization and nutrient management program can be achieved to solve these problems and maintain fertilizer effectiveness. More studies on fertilizer use for crops are needed in the future.

Most soils in Taiwan are acidic. It is necessary to correct their acidity, and supply Ca or Mg to the soil annually or on alternate years.

In order to reduce rice production, conversion of paddy fields to other crops is currently an important agricultural policy. The existence of a plow pan in the soil is a constraint to upland crop production. Partial breaking of the plow pan and deep banding of fertilizer increase crop yields significantly. However, rice production is still needed to maintain soil fertility. A rotation system which includes rice and legume is needed, and must be carefully and systematically tested on a range of sites.

A large amount of organic wastes from livestock farms is not being used on agricultural land. This is a kind of energy loss, as well as a source of environmental pollution. Stricter regulations are needed to prohibit the discharge of livestock manure and encourage its use.

Since the use of biofertilizers reduces the need for chemical fertilizer applications to soybean and muskmelon, more studies of other crops are needed in the future.

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DISCUSSION

Dr. Hong referred to the point made in Dr. Huang's paper that the available phosphorus content in Taiwan's soils is rather low. However, a large amount of phosphate fertilizer is applied each year (about 83 kg/ha in 1992). If more phosphorus is applied than is required by the plant, it tends to accumulate in the soil. Dr. Hong asked if there was any indication that this had been happening in Taiwan over the past ten years. Dr. Huang replied that there are some signs of this, but that phosphate availability is still low. He explained that under conditions of low pH and poor soil properties, when a paddy field is converted to upland crops there is a change from ferrous phosphate to ferric phosphate. Ferric phosphate is less effective as a plant nutrient source than the ferrous form, and Dr. Huang felt that the level of available phosphorus in Taiwan's soils is still too low.